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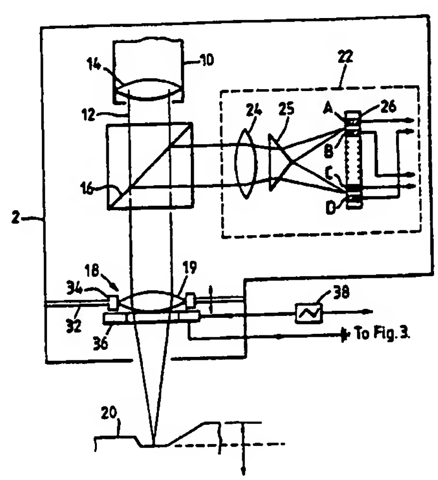
(54) Title: OPTICAL MEASURING PROBE

(57) Abstract

In an optical measuring probe a laser beam generator (10) produces a laser beam (12) which is directed through a half-silvered miror (16) and a focussing lens system (18) to form a focal spot adjacent a surface (20) to be measured. Light reflected from the surface (20) is deflected by the half-silvered mirror (16) onto a focus detector module (22) which determines when the focal spot coincides with the surface. To make measurements of the position of the surface the lens system (18) comprises a lens mounted on a planar spring (32) for oscillation at a pre-selected frequency through a pre-selected amplitude by an electro-magnetic coil system (34, 36) driven by an oscillator (38) whereby the focal spot passes through the surface (20). The focus detector module produces a signal each time the focal spot coincides with the surface. The signals are sent to the machine on which the probe is mounted, and the x, y and z co-ordinates of the machine scales are read and stored each time a signal is received. Since the position of the probe with respect to the machine spindle is fixed and the position of the lens within the probe in the undeflected state of the spring is also fixed, the position of the surface can be determined accurately and with high frequency for scanning purposes. For increasing the range of operation of the probe a servo-system for moving the probe as a whole in dependence on signals generated from the focus detection circuit, and a focus detection circuit of increased range are also described.



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OPTICAL MEASURING PROBE

The present invention relates to optical probes for use in making measurements of surfaces.

It is known in laser disc scanning systems to focus a laser spot onto a moving surface and to receive reflected light from the surface. The moving surface is formed with an array of spaced projections all of the same height and the laser beam is arranged to be in focus only at one height. Thus the light reflected from the surface will vary in intensity as the projections pass through the beam. By detecting the variations in the intensity of the reflected light and producing electrical signals corresponding thereto, a pattern of electrical signals can be made to correspond to the pattern of the projections on the disc.

Such a system however simply reproduces the pattern electrically and has no capability for measuring the heights of the projections.

It is also known from UK Patent Specification No. 2,183,418A to mount the final lens of such a system for limited movement along the axis of the laser beam and to use a signal from the detector as an error signal for a servo system which moves the lens so that as the spot moves out of focus the error signal sent to the servo-system causes the servo-system to move the lens to bring the spot back into focus. By measuring the movement of the servo-system, which is proportional to the change in height of the surface, the system can be given a limited measuring capability.

An object of the present invention is to provide a simplified laser scanning system with the capability of

making limited measurements of the surface, and which avoids the need for a servo-system to measure the lens movement.

This object is achieved in accordance with the invention as claimed in the appended claims by focussing a light beam through a lens system onto a surface to be measured, causing the focal point of the beam to undergo an oscillating movement of known frequency and amplitude along the axis of the beam and detecting the instantaneous positions of the lens when the focal point of the light beam is co-incident with the surface by means of a focus detector module.

Since the focal point of the light beam will oscillate between known points above and below the surface as the surface moves through the beam, by detecting the instants in the cycle of the oscillations when the focussed spot at the focal point of the light beam coincides with the plane of the surface, the height of the surface at the position of such coincidence can be determined relative to any previous position.

The advantage of such a system is that only a relatively simple focus detection circuit is required to detect the in-focus condition of the spot, and no high speed servo-system is needed to keep the spot in focus. The light beam is preferably collimated or is a coherent light beam from a laser beam generator.

Examples of the invention will now be described with reference to the accompanying drawings in which :

Fig. 1 shows diagrammatically the layout of the components of the optical measuring probe and focus detector module of the present invention,

Fig. 2 shows the focus error signal produced by the

focus detection circuit,

Fig. 3 is an electric circuit diagram illustrating the electrical components required for converting the detector signals of Fig. 1 into measurement information,

Figs. 4a to 4c shows the wave form diagrams of some of the electrical components shown in Fig. 3, and

Fig. 5 shows diagrammatically the system on the spindle of a co-ordinate measuring machine.

Referring now to Fig. 1 there is shown an optical measuring probe having a housing 2 within which is mounted a laser beam generator 10 of any convenient type e.g. a semi-conductor laser. The laser beam generator includes a lens 14 which produces a coherent beam 12 which is directed to a half-silvered mirror 16. From the mirror the beam 12 passes through a second lens system 18 which focusses it down to a very small spot adjacent to the surface 20 to be measured.

Light reflected from the surface 20 returns through the lens 18 system to the mirror 16 where it is reflected through 90° to a focus detector module 22 within the housing 2. Detector module 22 includes a focussing lens 24, a prism 25, a photo-diode detector array 26 and a focus detection circuit 27. The photo-diode detector array 26 produces an output in dependence on the amount of light falling on it from the mirror. The reflected light from the mirror 8 is focussed by the lens 24 onto the plane of the photo-diode array and passes through the prism 25 which splits it into two beams directed towards two specific pairs of photo-diode detctors A,B and C,D within the array.

In order to provide a signal of variable intensity from the output of the focus detector module 22 for

measuring purposes, the lens system 18 comprises a lens 19 which is mounted from the housing 2 of the probe by means of a planar spring 32. The spring 32 provides support for the lens against transverse or rotational movement, but allows movement to take place in a direction axially of the beam 12 within a limited range. Such movement is provided by a drive mechanism of any convenient type, e.g. a piezo electric mechanism, or as shown in the Figure, an electro-magnetic device, consisting of a ring magnet 34, (or a plurality of individual magnets) surrounding the lens and operated by a coil 36 driven by a voltage controlled oscillator 38.

Since the focal point of the lens is at a constant distance from the lens, the oscillating movement of the lens in the direction of the light beam will cause the focal spot to move alternately above and below the plane of the surface 20 of the workpiece. The focus detector module 22 determines when the focal spot is coincident with the surface 20 as will be described below with reference to Fig. 3.

The range of vertical movement of the lens, and hence of the focussed spot can be pre-determined by a suitable choice of spring and magnetic drive.

Thus if, for example, the frequency of the oscillator is 50 cycles per second and the range of movement of the focussed spot is ± 100 microns then the spot will move 200 microns in one fiftieth of a second and will be focussed on the surface 20 twice in that period. If the surface does not move, or has no variation in height, and if the probe is initially set up so that the spot is focussed on the surface in the centre of the range of movement of the lens, i.e. in the

undeflected state of the spring, the two signals from the detector as the spot focusses twice will occur half-way through and at the end of each cycle of the oscillation respectively. Where a change in height of the surface occurs, the signals will occur either earlier or later in the cycle, and a timing device in a processing part of the probe electrical circuit will enable that position to be determined as will be described hereinafter with reference to Fig 3.

Determination of the instant at which the focal point of the beam 12 lies on the surface 20 is as follows:

The components of the focus detector module 27 are arranged such that when the light beam 12 is focussed onto the surface 20, with the spring 16 in its central, i.e. unstrained position, the reflected light will be focussed towards the spaces between the photo-diodes A,B and C,D in each pair. The light spots formed by the prism in the spaces are arranged, in this focussed condition, to equally overlap the edges of the two detectors A,B and C,D on each side of the respective spaces. When relative movement between the surface 20 and the probe causes the focal point of the light beam to move to a position above or below the surface 20, the two beams leaving the prism 25 will become more or less divergent, and the spots formed by them on the photo-diode pairs will both move either more towards the outer two detectors A and D, or towards the inner two detectors B and C. The result is that the amount of light received by the outer two detectors A and D will either increase or decrease and at the same time the amount of light received by the inner two detectors B and C will respectively decrease or increase.

Referring now to Fig. 3 the outputs of the outer two

detectors A and D are connected at a summing junction 40, and the outputs of the inner two detectors B and C are connected at a summing junction 41. The outputs of the two summing junctions 40 and 41 are subtracted at a further junction 42 which produces an output 43 in the form shown by the curve 44 of Fig. 2. The distance x, between the two peaks of the curve, gives the working range of the detector as the focal point of the light beam 12 moves up and down, and the amplitude of the peaks y, gives a focus error signal. A zero-crossing detector circuit 45 (known per se) is used to determine the point 0 on curve 44 in the working range of the detectors at which the difference in the outputs of the outer and inner detectors is zero, which indicates that the beam 12 is focussed on the surface 20. The zero-crossing detector circuit produces an output 46 in the f+orm of a pulse every time a zero-crossing is detected.

However, the optical measuring probe in operation will often be outside the working range x of the focus detectors, since this is limited to a few microns of relative movement between the surface 20 and the probe. As the surface moves further away from the focal point of the light beam, the reflected light becomes more diffused, and the spots formed by the prism 25 on the detector pairs A,B and C,D become rapidly larger and less intense until they cover both detectors, and the difference signal from junction 42 tends to zero. This would give a false trigger signal from the zero crossing detector at point x_1 or x_2 outside the working range of the detectors.

In order to avoid this and to increase the working range of the probe a validating circuit is introduced into the focus detection circuit and which is arranged

to determine when the zero-crossing point on curve 44 lies inside the working range of the detectors and outputs a signal accordingly. Such a validating circuit is described in our co-pending UK application entitled "Focus Detection Circuit for use in Optical Measuring Systems" filed on 20 October 1987.

Those parts of the detector array 26 other than the focus detectors A,B C and D will be illuminated by light spilling around the focus detectors when the light spots generated by the prism become enlarged as the surface 20 moves away from focus. The outputs of all of the remaining detectors i.e. except the focus detectors A,B C and D are connected together to form a single output G. The remaining detectors are hereinafter collectively referred to as a guard detector 47.

The focus detector module will only operate correctly when the light from the prism forms two defined spots on the focus detector pairs A,B and C,D. If this is not the case, i.e. when the light beam 12 is far from beng focussed on the surface 20, the guard detector 47 and the focus detector pairs will be weakly illuminated by the received light. The ratio of the signals from the guard detector and the sum of the signals from the detector pairs A,B and C,D will be proportional to the areas of the respective detectors.

As the probe approaches focus, the intensity of diffuse illumintion across all of the detectors will increase, and the ratio of the signals described above will remain constant until the point is reached where the two spots from the prism begin to be defined on the focus detector pairs A,B and C,D. The output from the guard detector will then start to drop while the output

from the focus detector pairs increases. A threshold ratio can be set at the level at which the focus detector pairs A,B and C,D are within their working range and a validation signal generated when this level is reached. Only those zero-crossing signals developed while the validation signal is present will then be sent to the machine as true measurement signals.

In Fig. 3 the part of the focus detection circuit for providing the validation signal is shown as including a divider 52 which receives the output G from the guard detector as a first input, and the sum of the ouputs of the four focus detectors A,B, C and D via a summing junction 54 as a second input F. The divider provides an output VR equal to the ratio of inputs G:F. The output VR of the divider is passed to a comparator 56 which also receives a reference voltage V ref. and outputs the validation signal SV when the ratio G:F falls below the threshold value.

As described above the signals SV from the validation circuit and 46 from the zero-crossing detector are arranged to be positive and are passed to an AND gate 48 which produces a validated output pulse 49 from the detector module when signals SV and 46 are present at the same time.

By moving the surface with respect to the probe, or by moving the probe with respect to the surface on a co-ordinate measuring machine, the profile of the surface can be measured as follows:

The validated output pulse 49 of the focus detector module is fed to the scale reading apparatus on the measuring machine in a known manner to initiate reading and storing of the scale measurements.

The position of the surface in the x-y horizontal plane may be determined by reading the machine scales every time a validated detector output pulse is received and storing the readings in the machine memory. The position of the probe is known in the vertical axis by reading the machine scale, and the position of the focussed spot in the undeflected state of the spring is determined in the x,y and z axes by an initial calibration of the machine with the probe fitted.

As the relative movement is generated between the probe and the surface one hundred, readings per second of the vertical position of the surface can be made using the validated output signal and on each occasion the x-y co-ordinates of the surface will be read from the machine scales. Where the scale reading devices cannot provide readings at sufficient speed, the scales may be read at less frequent intervals, e.g. twenty times a second and the x,y measurement interpolated, if required, in between.

To determine the actual position of the surface relative to the probe, the timing of the in-focus signals from the focus detector module relative to the lens movement cycle is determined. That is whether or not the in-focus signals are occurring earlier or later in the cycle than previous signals.

Fig. 4a illustrates the movement of the focal spot relative to the surface 20, as the surface travels from right to left of the Fig. While the surface is level the in-focus points are evenly spaced at mid range of the movement of the lens.

Fig. 4b shows the frequency of the validated in-focus

pulses 49 produced by the focus detection circuit and it can be seen that while the surface remains at a constant distance from the lens the pulses are evenly spaced. When the surface moves closer to the lens however, the pulses generated during the upward movement of the lens are delayed while the pulses generated during the downward movement of the lens are early compared to the previous pulses.

The timing circuit shown in Fig. 3 determines the interval $\triangle$T by which the pulses are early or late.

Referring to Fig. 3 the oscillator 38 is arranged to provide a triangular wave form so that the relationship between the movement of the lens and time is linear. The triangular waveform is converted to a square wave form in a convertor 58 and the period of the square wave is identical with the period of the triangular wave.

Fig. 4c shows the relationship of the square wave to the validated pulses coming from the focus detector circuit.

As can be seen the rising and falling edges of the square wave are in time with the pulses when there is no relative movement between the surface and the probe. When relative movement occurs a variation $\triangle$T occurs.

The timing circuit 60 receives the square wave from converter 58 and a clock pulse 62 from a clock pulse generator 63 with a frequency in the Mega Hertz range, and compares the relative timing of the rising edge of the square wave with the arrival of the detector pulse 49 and computes the time difference $\triangle$T which is proportional to the relative movement. $\triangle$T may be

described as positive if the pulse appears before the rising edge and negative if it appears after the rising edge.

As seen from Fig. 4c the periods $-\Delta T_1$, $-\Delta T_2$, $-\Delta T_3$ can therefore be calculated and the relative movement of the surface and probe determined.

This value is passed to a micro processor 64 along with the reading of the vertical machine scale and an ouput provided which shows the position of the surface on the vertical Z co-ordinate axis.

Thus the invention provides a scanning probe which is capable of measuring the position of a surface within certain limits without the need for a servo-system.

If greater movement in the vertical direction is needed to enable measurements of surfaces to be made where the relative movement between the probe and the surface is outside the limits of movement of the lens system 18, this can be achieved by driving the vertical machine spindle up and down in known manner as shown in Fig. 5. This will require an error signal to be sent from the detector circuit to the machine when the change in height of the surface exceeds a pre-determined limit say 25 or 50 microns where the total range of the lens oscillation is 200 microns. The error signal can be used to cause the motor driving the vertical spindle of the machine to move the spindle in the appropriate direction in known manner to bring the surface back to the middle part of the range of movement of the focussed spot.

The error signal can be the signal ΔT produced by the timing circuit which will be in digital form, and ,

where the machine has digital drive, can be passed directly to the machine drives. Otherwise the signal would be passed via an analogue to digital converter referenced 66 in Fig. 4 and an analogue signal sent to the machine. The signal is made proportional to the size of the error ΔT so that the greater the error the faster the machine will drive the spindle to restore the surface to the middle of the range of movement of the probe lens.

Fig. 5 shows diagrammatically a machine spindle 70 on which the probe is mounted and a drive 72 adapted to receive the error signal 49 from the detector to move the spindle up or down as required. Such mechanisms are well known in the art and need not be described in detail in this specification.

Although the embodiment described above uses an oscillator to move the lens system 18, it is clear that the necesary relative movement between the focal point of the light beam 12 and the surface 20 could be achieved by other means. For example the laser beam generator 10 could be mounted for oscillating movement in which case the collimating lens 14 would need to be mounted on static structure in the probe housing separately from the laser body.

In another alternative arrangement the probe housing itself including the detector system may be mounted within an outer housing for oscillating movement. If such a system is used then the probe may also be mounted in such a manner that it has the capability of moving the focal spot in the x and y directions of the co-ordinate measuring machine. To accomplish this the probe may, for example, be mounted on two pairs of parallel leaf springs in series, each pair of which may

be driven in like manner to the lens drive system described above to provide a range of movement of say 100 microns in each of the two directions. A mounting system of this type is described in relation to a different probe system in our co-pending patent application of the same date entitled "Position-Determining Apparatus".

Such a system would require two more detectors to provide signals depending on the position of the reflected spot in the x and y directions within the range of movement of the two drive systems. Such x and y measurement capability would allow more accurate determination of the position of edge surfaces with very steep slopes which could be missed with a one-axis system described in detail above. Once again, if a greater range of movement was required the detectors could be arranged to send error signals to the drive mechanisms of the co-ordinate measuring machine to enable the greater movements of the machine slides in the x and y directions to be added to the smaller movements of the electro-magnetic drive system of the probe.

In a further alternative embodiment the laser beam generator 10 and lens 14 are replaced by a system for producing a collimated light beam.

It will also be understood that part or all of the circuitry described in Fig. 4 may be incorporated within the probe housing 2.

CLAIMS:

1. An optical measuring probe comprising a light source for generating a light beam, means for focussing the light beam to a focal point, a focus detector module for receiving light from a surface to be measured which is placed in the path of the light beam said focus detector module being capable of providing an output signal when the focal point of the light beam is coincident with said surface, characterised in that means are provided for causing the focal point of the light beam to oscillate at a pre-determined amplitude and frequency relative to said surface whereby when said surface lies within the range of oscillatory movement of the focal point of the light beam a plurality of signals will be produced by the focus detector module from which the position of the surface is determined.

2. An optical measuring probe as claimed in Claim 1 in which the light beam generated from the light source is a collimated or coherent light beam.

3. An optical measuring probe as claimed in Claim 1 in which the means for focussing the light beam to a focal point comprises a lens system.

4. An optical measuring probe as claimed in Claim 3 in which the lens system comprises a lens, and a resilient mounting for the lens which allows movement of the lens in the direction of the light beam while supporting the lens against rotation about, or transverse movement relative to, an axis extending in the direction of the light beam.

5. An optical measuring probe as claimed in Claim 4

in which the means for causing the focal point of the light beam to oscillate comprises drive means connected to the lens system and an oscillator arranged to cause oscillation of the drive means.

6. An optical meauring probe as claimed in Claim 1 in which the focus detector module comprises a focussing lens, a prism, a photo-diode detector array and a focus detection circuit and wherein the focus detection circuit produces two output signals during each cycle of oscillation of the focal point of the light beam the probe further comprising a timing circuit, a clock pulse generator and means for providing a square wave signal derived from the oscillator, the timing circuit being arranged to receive as inputs the signal from the focus detection circuit, the square wave and a clock pulse from the clock pulse generator and to provide an output indicative of the period of time ΔT by which the output signals from the focus detector module occur earlier or later in the cycle of oscillation of the focal point of the light source compared with a previous one of said output signals, and the probe further comprising means for deriving signals indicative of the position of the surface relative to the probe from the output of the timing circuit.

Fig.1.

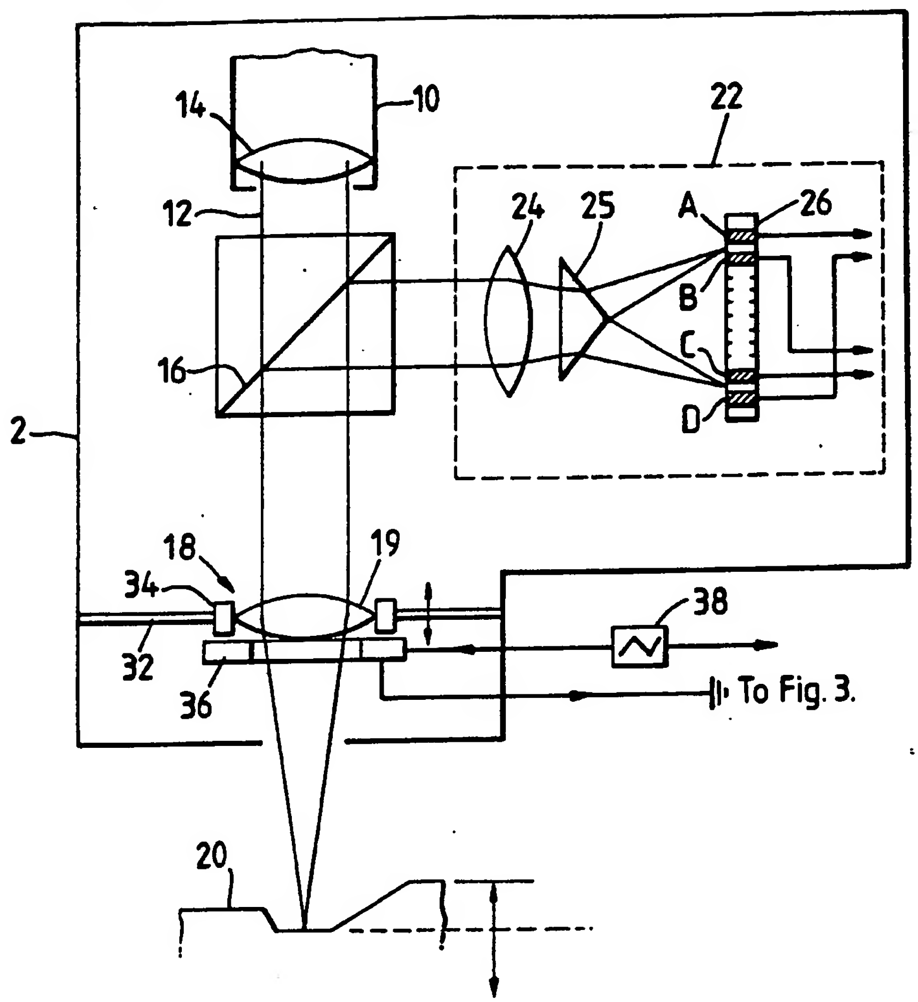

Fig.2.

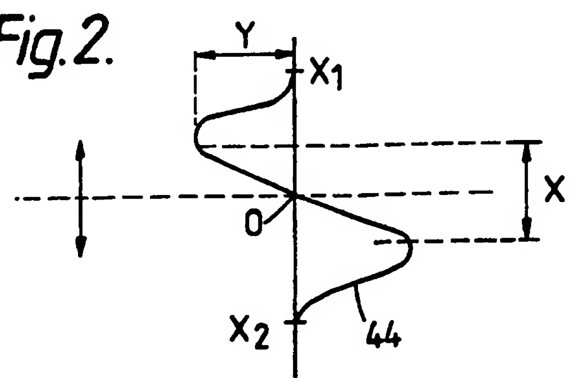

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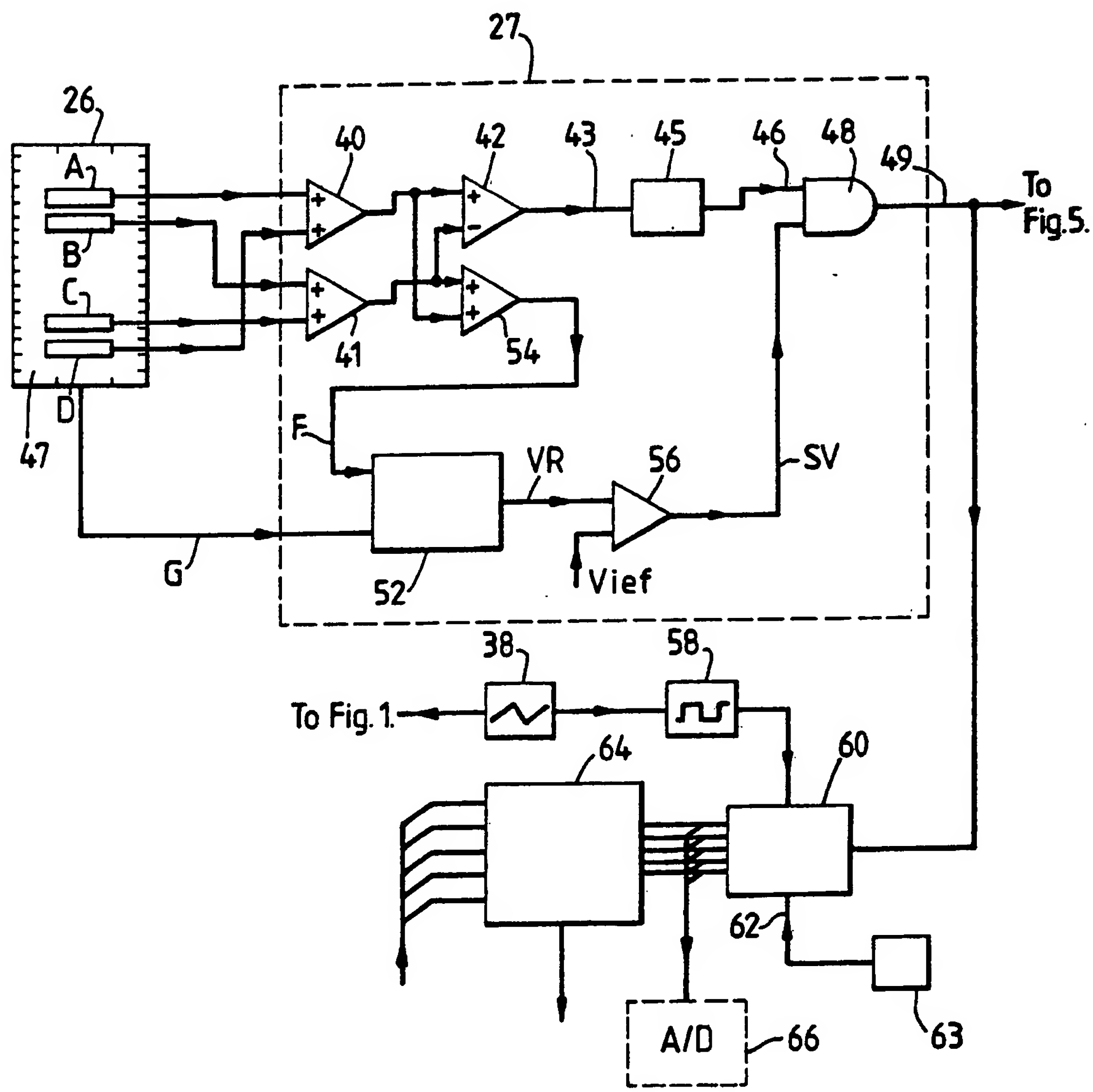
Fig. 3.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To Fig.5.
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Fig.4a.

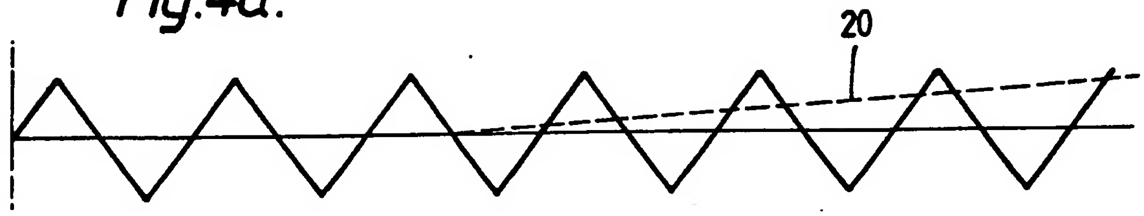


Fig.4b.

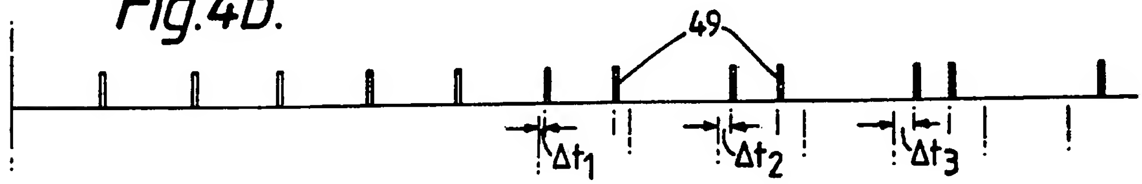


Fig.4c.

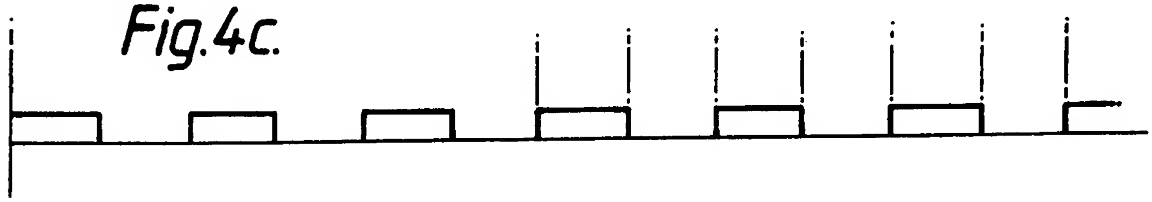
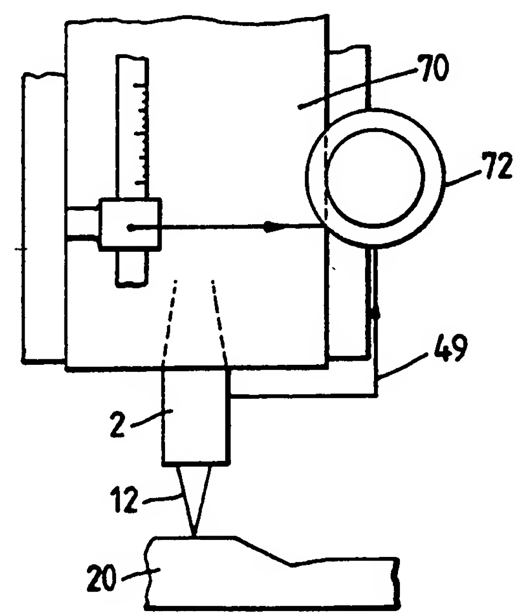


Fig.5.



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INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 87/00746

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [8]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: G 01 B 11/02; G 01 B 11/03

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	G 01 B 11/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	DE, A1, 3322712 (DAIMLER-BENZ) 10 January 1985 see claims; page 5, line 5 - page 12, line 36; figures --	1,3,4
X	US, A, 4527893 (F.M. TAYLOR) 9 July 1985 see figures 3,4,5; column 5, line 41 - column 10, line 25	1-3
Y	--	4,5
Y	Patent Abstracts of Japan, volume 11, no. 5 (P-533)(2452), 8 January 1988, & JP, A, 61182508 (HITACHI LTD) 15 August 1986 see the abstract and figure --	4,5
A	US, A, 4355904 (N. BALASUBRAMANIAN) 26 October 1982 see the whole document --	1-6
A	US, A, 3589815 (H.L. HOSTERMAN) 29 June 1971 see the whole document ./. --	1-6

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
2nd February 1988	15 MAR 1988
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
P,X	EP, A1, 0198557 (B.V. OPTISCHE INDUSTRIE "DE OUDE DELFT") 22 october 1986 see the whole document --------	1,2,4,5

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 8700746 SA 19025

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 23/02/88
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-A- 3322712	10-01-85	None	
US-A- 4527893	09-07-85	None	
US-A- 4355904	26-10-82	US-A- 4204772	27-05-80
US-A- 3589815	29-06-71	None	
EP-A- 0198557	22-10-86	JP-A- 61239106 NL-A- 8501100	24-10-86 03-11-86

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82